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AN INVESTIGATION OF ALTERNATIVE MATERIALS FOR MINERAL WOOL PRODUCTION

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AN INVESTIGATION OF ALTERNATIVE MATERIALS FOR MINERAL WOOL PRODUCTION

by

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SUMMARY

Basalt, trap rock, diopside and their mixtures with limestone or quartz were successfully electromelted and fiberized. Prior to fiberization tests, viscosity, a critical parameter for mineral wool formation, was investigated by a high temperature viscometer. Wool samples produced at different fiberizing temperatures were collected and the fibre diameters measured by image analysis. The average diameters of the wool samples were mostly in the acceptable range for quality standard. The inherent reducing condition in CANMET's electric furnace caused iron oxides in the basalt and trap rock melts to be reduced to metallic iron. This reduction changed the melt viscosity and consequently made the control of the fiberization process somewhat complex. It is suggested that a gas fired furnace or an electric furnace with oxide refractory lining and non-submerged electrodes could circumvent this problem.

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UNE RECHERCHE DES MATÉRIAUX POSSIBLES POUR LA FABRICATION DE LA LAINE MINÉRALE

par

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SOMMAIRE

On a électro-dissous et mis en fibres avec succès le basalte, la roche à nid, le diopside et leurs mélanges avec la pierre calcaire ou le quartz. Avant les tests sur la mise en fibres, on a fait des recherches avec un viscomètre à haute température sur la viscosité, un paramètre critique pour la production de la laine minérale. On a collectionné les échantillons fabriqués aux différentes températures de mise en fibres et les diamètres des fibres mesurés par l'analyse de l'image. Les diamètres moyennes des échantillons de la laine étaient, la plupart, dans une plage acceptable du type de qualité. La condition de réduction inhérente au pour électrique du CANMET ont originé des oxydes de fer dans le basalte et la roche de nid qui se sont réduits au fer métallique. Cette réduction a changé la dissolution du viscose et par conséquent a rendu la méthode de mise en fibres un peu complexe. On a suggéré qu'un four à gaz ou un four électrique avec une couche refractaire et des électrodes non-immersées pourraient faire échouer ce problème.

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INTRODUCTION

This research project in thermal insulation is in line with EMR's policy of promoting conservation of energy and materials. The project was designed to evaluate electro-melt techniques for the production of mineral wool from the traditional material, blast furnace slag and, as well, from alternative materials such as diopside, basalt, and trap rock. The electric furnace is deemed more energy efficient and environmentally acceptable. In addition, fine as well as coarse raw materials may be processed, thus recycling of waste shot is feasible.

The work with blast furnace slag was described in a previous report (1). This report outlines work with the noted alternative materials.

EXPERIMENTAL WORK

A three electrode, 150 kVA electric-arc furnace was installed and commissioned at CANMET in 1979 (2). The furnace uses a graphite crucible to hold the charge and includes a mechanism to allow bottom gravity flow of the glass melt. A kWh meter is used to determine energy consumption during the melting process and also to establish the relationship between feed, feed rate, and electrical energy consumption. The furnace is described in detail in Reference 2.

The fiberizing apparatus (air jet) designed and used for this work consisted of a venturi type nozzle with an oval-shaped opening that measured 1.6 x 20.6 mm. This was placed with the longer axis (20.6 mm) horizontal and at right angles to the flow of molten glass, approximately 25 mm below the bottom of the tap hole and 25 mm from the stream. Compressed air fed through the nozzle dispersed the stream into fine globules which are attenuated into fibres by air resistance during flight.

SAMPLES

The chemical compositions of the raw materials used in this study are listed in Table 1.

Table 1 - Chemical composition of samples

Sample	SiO_2	Al_2O_3	CaO	MgO	Total Fe	Na_2O	K_2O	LOI
diopside	51.1	1.2	27.1	16.5	0.3	0.1	-	0.4
quartz	99.9	-	-	-	-	-	-	-
trap rock	33	23.6	11	5.8	10.5	-	-	-
limestone	12.9	4.7	40.8	1.1	1.2	-	-	34
basalt	51.4	14.1	10.1	6.3	9.0	3.1	0.5	-
waste limestone	11.2	2.5	44.3	1.8	0.5	0.2	1.0	37.6

PROCEDURE

A 5-8 cm layer of blended charge materials (2.3 kg) was placed in the bottom of the crucible and topped by a thin layer of minus 6 mm coke. The coke, used to initiate the electrical arc, covered an area large enough to engage all three electrodes. The power was turned on and the crucible raised until the arc was established. As the arc intially heated and then melted the solid materials, the volume of the charge decreased. Arcing was maintained by raising the crucible. When a molten pool of material was formed, the electrodes were immersed in the melt which then became an ionic conductor. The unit then functioned as a resistance-heating furnace. The depth of the molten bath was increased by feeding the remaining 6.7 kg of the charge through the feeder port continuously over a 20-25 min period.

The power consumption, indicated by the kWh meter and directly related to the actual amount of heat input into the charge materials, was used to determine when the approximate desired temperature had been reached. At this point the power was shut off and the crucible quickly lowered. An immersion-thermocouple-lance was used to measure the melt temperature. The crucible was then raised and the required temperature reached by either continuing to supply electrical power to the furnace or by allowing the furnace charge to cool. The melt temperature was closely monitored during this critical period.

When the desired temperature was reached, a graphite plug in the bottom of the furnace was "punched" through the tap hole. The melt temperature was monitored by an optical pyrometer as the melt flowed through the hole. The stream of molten material was subjected to an air-blast at right angles to the stream, at a pressure of 620 kPa and at a flow rate of 1.2 m^3/min. Fiberization took place as the liquid globules formed

by the impact were drawn out by air resistance during flight. The stream of wool was sampled at different fiberizing temperatures by a hand-held sampler net. The bulk of wool was deposited in a collecting chamber.

RESULTS AND DISCUSSION

BASALT

Before initiating the fiberization experiments, the viscosities of the basalt sample were measured under an EMR contract at the University of Toronto. Viscosity has a great influence on the quality of the fibres (3). Fibre diameter is dependent on melt viscosity. A viscous melt produces coarse fibres. Coarse fibre wool is more brittle, bulky and unpleasant to handle and has large air pockets formed by the interlacing fibres which contribute to heat loss by convection. Fine fibres tend to pack more closely. The non-conducting air space is decreased with packing but the bulk density of the wool is increased. A reasonable compromise for acceptable wool fibre diameter would be from 3 to 13 µm. Table 2 presents viscosity values at different temperatures.

Table 2 - Viscosities of the basalt sample

Temperature °C	1450	1505	1529
Viscosity 10^{-3} Pa.s (cp)	1578	1152	963

Zhilin observes that good quality fibre is obtained when the viscosity of the melt is about 500 cp (centipoise, 10^{-3} Pa.s) at 1500°C, or 1500 cp at 1400°C (4). The viscosity values in Table 2 are higher than those observed by Zhilin indicating that higher fiberizing temperatures should be employed. Two fiberization tests were performed, one at 1500°C and the other at 1600°C.

Test at 1500°C

The wool produced was of a dark green colour and was very coarse. The fibre average diameter measured by image analysis was 50 µm indicating that the wool was too coarse (5). Reducing conditions prevail in the electric

furnace because the crucible and the electrodes are made of graphite. In addition, the electrodes are submerged in the melt. Iron oxides in the charge material are reduced and separated from the melt as a metal phase. A metal phase of 220 g was produced. The chemical analysis of the frozen melt gave the total iron content of 6.2% compared to 9% in the basalt feed. Iron oxides are good fluxing agents. The reduction of iron oxides should increase the viscosity of the melt. This was confirmed by the fact that the wool produced was coarser than predicted by the viscosity data. The viscosity of the charge materials was measured in an inert argon atmosphere which resulted in no reduction of the iron oxides.

Test at 1600°C

A good white colour wool was produced with an average fibre diameter of 7.1 µm. A metal phase of 550 g, much larger than that produced at 1500°C, was obtained and the iron content in the frozen melt decreases to 3.7%. The higher temperature, thermodynamically, favours iron oxide reduction. The white colour of the wool also indicates that most of the iron oxides had already been removed from the system. The much higher fiberizing temperature greatly reduced the melt viscosity and consequently resulted in finer fibres.

TRAP ROCK

Three tests were carried out with trap rock and trap rock/calcined limestone mixtures.

Test 1

The viscosity values are presented in Table 3. Nine kilograms of trap rock were used as the charge material. Wool samples were taken at 1475 and 1420°C. Both wool samples were of a dark green colour. The average fibre

Table 3 - Melt viscosities of the trap rock sample

Temperature °C	1395	1450	1470	1500
Viscosity 10^{-3} Pa.s (cp)	850	380	325	235

diameter for the wool obtained at 1475°C was 12.4 µm and that at 1420°C,14.4 µm. A metal phase of 250 g was produced. Again, the prevailing reducing conditions in the electric furnace caused the iron oxides to be reduced and separated out as a metal phase. This reduction of iron oxides resulted in melt viscosity increase and coarser fibres than predicted by the listed viscosity data in Table 3.

Test 2

The charge for this test consisted of 70% trap rock and 30% calcined limestone. The melt viscosities for this mixture are given in Table 4. With such low viscosity values, only fine fibres were expected to be produced. The melt was tapped at 1650°C and, when air blown, produced only fine mist-like particles and no wool. Apparently, the fiberizing temperature was too high and the melt viscosity too low. At 1575°C, very fine and short fibres were produced. At 1500°C, a soft fine wool was collected with an average fibre diameter of 2.4 µm. About 500 g of metal, more than twice the amount produced in Test 1, resulted even though the charge material for this test contained less iron oxides than that for Test 1. The reason is that the addition of CaO (calcined limestone) to the charge material increased the activities of the iron oxides which rendered them more reducible. The white colour of the wool also indicates that most of the iron oxides had already been removed from the system.

Table 4 - Melt viscosities of the 70% trap rock and 30% calcined limestone sample

Temperature °C	1470	1510	1550	1594
Viscosity 10^{-3} Pa.s (cp)	157	130	120	112

Test 3

The test charge was a mixture of 90% trap rock and 10% calcined limestone. Table 5 shows the viscosity data. Wool was sampled at 1530, 1440 and 1340°C. The average fibre diameter for those samples was 7.0, 15.3 and 24.3 µm, respectively. The wool formed at 1340°C was too coarse. All three wool samples were of a green colour. About 260 g of metal was produced, which is in between the amounts obtained in Tests 1 and 2. The

10% addition of calcined limestone in this test reduced the activities of the iron oxides compared with Test 2 but increased the activities compared with Test 1.

Table 5 - Melt viscosities of the 90% trap rock and 10% calcined limestone sample

Temperature °C	1325	1350	1450	1550
Viscosity 10^{-3} Pa.s (cp)	1650	1000	230	155

DIOPSIDE

Five tests were carried out with diopside, diopside/waste limestone, and diopside/quartz mixtures. Diopside contains little iron oxides (total iron content 0.3%). No metal phase was obtained and no problem of viscosity change due to reduction of iron oxides was encountered during the test. The melt viscosities for the five test charges had previously been measured at various temperatures by CANMET's high temperature viscometer. The results are presented in Table 6. The viscosity data indicate that at least test charges 4 and 5 should produce acceptable fibres according to Zhilin's prediction (4).

Table 6 - Melt viscosities of diopside charge mixtures

Test charge	Charge composition Wt %			Temperature °C - viscosity 10^{-3} Pa.s (cp)			
	Diopside	Quartz	Waste limestone				
1	90	0	10	1580-155	1545-173	1525-184	1405- 336
2	100	0	0	1580-170	1545-191	1520-215	1425- 426
3	90	10	0	1580-225	1545-257	1525-287	1435- 509
4	80	20	0	1580-438	1550-516	1525-633	1425-1173
5	75	25	0	1570-445	1545-528	1530-664	1430-1471

A summary of the fiberization results is shown in Table 7. All wool products were white in colour. Table 7 shows that for each test charge, fibre diameter increases as fiberizing temperature decreases. As previously discussed, when temperature decreases, melt viscosity increases and coarser fibre is produced. Table 7 also indicates that as quartz

Table 7 - Fiberization results

Test charge	Charge composition Wt %			Fiberizing temperature °C - average fibre diameter µm
	Diopside	Quartz	Waste limestone	
1	90	0	10	1520-3.0 ; 1380-4.3
2	100	0	0	1520-3.4 ; 1500-4.3
3	90	10	0	1640-2.2 ; 1520-3.6 ; 1480-4.4
4	80	20	0	1560-3.0 ; 1500-5.3 ; 1440-8.9
5	75	25	0	1570-3.4 ; 1530-4.3 ; 1460-6.5

(SiO_2) content in the test charge increases, average fibre diameter increases. It is known that the structure of molten silicates consists of a tetrahedrally bonded Si-O network. The addition of SiO_2, a network former, increases the size of unit in the silicate network, and consequently its viscosity. An examination of the fibre diameter data in Table 7 indicates that fibres produced for test charge 1 at 1520°C, test charge 2 at 1520°C, and test charge 4 at 1560°C are too fine. The average diameters of the other wool samples are in the acceptable range for quality.

CONCLUSION

Wool samples of a quality comparable with wool made from traditional blast furnace slag/sandstone mixtures, were produced from basalt, trap rock and diopside. Thus these rock-types appear to be suitable alternative materials for mineral wool production. Basalt and trap rock each contain significant amounts of iron oxides. The inherent reducing condition in CANMET's electric furnace converts these oxides to metallic iron. This

reduction changes the viscosity of the melt and makes the control of the fiberization process more complex. Perhaps, a gas-fired furnace or an electric furnace with oxide refractory lining and non-submerged electrodes would circumvent this problem and ensure better control of the fiberization process.

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POOR

QUALITY

ORIGINAL